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OPPORTUNITIES AND PROBLEMS IN BENEFICIATION AND EXTRACTIVE METALLURGY PRACTICES

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OPPORTUNITIES AND PROBLEMS IN BENEFICIATION AND EXTRACTIVE METALLURGY PRACTICES

by

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Introduction

1. The inseparable relationship of natural resources, their utilization, and industrial development is well known and understood by everyone concerned with national economic studies. The importance of minerals as a natural resource is impressive as shown by world production and consumption statistics. That the supply of mineral resources is diminishing is known by all who produce and utilize mineral raw materials. We mention it now because of the part it has in problems that confront the mineral-dressing and metallurgical professions.

2. The unprecedented industrial growth of recent years has taken a heavy toll of minerals from the more accessible, known deposits. High-grade portions of many ore deposits have been depleted, but, in maintaining a balance between supply and demand, the mining industry has achieved great success in exploiting progressively lower grade deposits of mineral raw materials. To support future industrial growth, new sources of mineral raw materials must be found, and technological progress must be accelerated to keep abreast of the need to utilize resources now considered noncommercial. Accomplishment of both these objectives is a reasonable expectation.

3. Persons who participated in the prodigious task of supplying past mineral raw material requirements pioneered avenues of technical progress that promise help in providing requirements of the future. This is significantly true in the field of minerals beneficiation. In the past 60 years particularly, these men discovered and successfully developed new processes, devices, and machines that greatly advanced mineral dressing technology. Exact scientific knowledge regarding the behavior of minerals under variable treatment conditions was disclosed by patient research during the same period in order to provide a solid foundation for future process developments.

4. This paper briefly reviews the present status of ore beneficiation in the United States with particular reference to processing low-grade, disseminated, and refractory ores. Mention will be made of the important role of chemical extractive metallurgy as applied to ores not amenable to physical treatment by present methods. Remarks on the application of technology to the development and exploitation of mineral deposits in less developed parts of the world will constitute the closing portion of the paper.1/

1/ Selected Bibliography included for reference purposes.

5. With but few exceptions, all minerals produced in the United States, even sand and gravel, currently are subjected to some type of treatment prior to use. The processes involved in beneficiation cover not only minerals in which metals are the principal constituent, but also nonmetallic ores. In a broad sense, beneficiation may mean extracting quantities of mineral from an ore, to obtain a metal or nonmetallic constituent that is only a small percentage of the whole, or, contrariwise, removing small quantities of harmful impurities from an ore comprised almost entirely of the useful mineral. Concentrating copper, lead, and zinc ores by flotation and beneficiating iron ore by magnetic methods are typical examples of the first application. Removing iron oxides from glass sand exemplifies the second application.

6. Mineral-dressing engineers use various physical and chemical characteristics of minerals to obtain a desired separation. Size, shape, and specific gravity; color and luster; electrical conductivity; magnetic susceptibility; hardness and toughness; surface energy; and other inherent or artificially induced properties are utilized to separate the economic minerals from the unwanted gangue materials. Choice of method for beneficiating a specific ore depends primarily on the results of amenability tests in the laboratory.

Handsorting and Cobbing

7. Handsorting and cobbing is the simplest and most direct process for separating broken ore into classes according to grade. As a beneficiation process it serves in several ways, the most important of which are to remove waste rock or high-grade mineral masses from ore before it is ground for subsequent processing and to separate ore constituents into waste and shipping-grade products. The process is especially applicable to ores containing large, easily distinguishable mineral crystals or masses occurring in narrow vein structures that must be mined with much country rock. Disseminated and complex ores that require fine grinding for mineral liberation generally are unsuited to the process.

8. Handsorting and cobbing is not a common practice in the United States because of the scarcity of applicable ores and the high cost of labor. Mechanical cobbing is considered profitable under some circumstances, however, and is still being done in a few cases to upgrade mill feed, for example, at a National Lead operation in upper New York State where titanium and magnetite concentrates are produced. After the ore is crushed, approximately 20 percent of the mined ore is rejected by a cobbing operation that involves conveying a screened intermediate-size (plus 7/16 inch) crusher product over magnetic head pulleys. Pieces containing practically no magnetic material are rejected to waste, and magnetic particles are directed to a third crushing stage ahead of milling operations.

9. Outside the United States, handsorting and cobbing is an extensively used method to upgrade mill feed and to obtain shipping-grade mineral products. Chromite in Pakistan, manganese in Indonesia, antimony in Bolivia, and fluorite in Mexico are but a few of the minerals and countries that offer examples of skillful handcobbing operations. In each operation, a high-grade shipping product is obtained. The rejected material is sorted into two products, a waste product and a middling product that is saved for further processing at some future time.

10. Recovery of mineral in cobbed shipping products is usually below that obtainable by mechanical concentrating methods, but there are compensating advantages to commend the practice, particularly in countries where the cost of labor is not prohibitive. Market specifications for many mineral products, including those mentioned, limit the percentage of contained fine material as determined by screen analysis. Handcobbing minimizes the amount of fines produced, and their percentage in the salable product can thus be effectively controlled. The more obvious advantages of handcobbing are related to operational requirements other than labor; capital investment in equipment is negligible, and the availability of water and power is unimportant. Therefore, if a market for the product exists and if the ore is amenable to beneficiation by handcobbing, small mines can be made productive without first having to develop ore reserves to protect a large capital investment. For what are typically small operations, such as the recovery of feldspar, sheet mica, beryl, and spodumene from zoned pegmatites, handcobbing is more practical than fine grinding and flotation, not withstanding the higher mineral recovery achieved by flotation.

Gravimetric Concentration

11. The concentration of ore fractions, minerals, and metals according to differences in their specific gravity is a process worthy of special distinction; it might be called a process of first and last resort. It is the preferred method for concentrating some minerals and is accepted for the concentration of others only after processes with greater appeal have failed to perform satisfactorily. As a first resort, it is selected for the recovery of gold and valuable minerals found in alluvial deposits and for the concentration of lode minerals such as fluorite and chromite when they can be liberated from their ores at coarse size. Fluorite and chromite are given as examples because market specifications and market preference for metallurgical-grade products generally limit the acceptable amount of contained fines. As a last resort, it is selected as being the best, even though not an entirely satisfactory, method of concentrating minerals, such as cassiterite and scheelite, that are not readily recoverable from lode ores in optimum-grade concentrates. Of course, many other intermediate applications of gravity concentration can be made, either as a preconcentrating step to obtain an enriched product for further treatment or as a single means of producing a finished concentrate when treating simple ores.

12. Jigs, shaking tables, heavy-media separators, and spiral concentrators have retained a position of preeminence among the scores of devices that have been tested as a means of concentrating minerals gravimetrically. Some less known devices designed for specific applications have enjoyed success for short periods but failed to survive in the field of general application. Riffled sluice launders, mechanical bateas, buddles, revolving and stationary convex tables, vanners, kieves and similar devices are outmoded but some are still in use. Currently, fan concentrators are successful in a limited field of application.

13. The dominant position jigs and tables have held for many years is being threatened by heavy-media separators and spiral concentrators. The precise separations obtained by sink-float fractionation over a wide density range when using magnetite or ferrosilicon in aqueous suspension as a parting medium cannot be duplicated by jigging unsized feed coarser than 1/8- or 3/16-inch. High throughput capacity and operating simplicity of cone, drum, or spiral separators

are other attractive features of this method For treating material less than 3/16-inch in size, varying treatment factors will influence a choice between diaphragm-type jigs, spiral concentrators, shaking tables, fan concentrators, and possibly others.

14. Operations that involve the daily treatment of low-value material in large volume tend to favor the use of diaphragm jigs or spirals, particularly as a preconcentrating step. Diaphragm-type jigs are used extensively for this purpose in gold- and tin-dredging operations; spiral concentrators, originally developed to recover chromite from the beach sands of Oregon, now dominate the beach sand industry of Florida for the ultimate recovery of ilmenite. Spirals also appear as scavenger units in numerous mill flowsheets; at a mill in Climax, Colo., they are used to recover wolframite from molybdenum flotation tailings. Their contemplated large-scale use for concentrating specular hematite ores of the Quebec-Labrador district is indicative of a growing trend in iron ore beneficiation practice.

15. For the production by gravimetric methods of high-grade mineral concentrates sold under a penalty-premium-type contract, shaking tables and mineral-type jigs are commonly used for treating material under 1/8-inch size. Hydraulic classification or screen sizing of feed and separate treatment of the resultant fractions is general practice for table concentration of typically amenable minerals, such as those of tungsten, tin, and chrome.

16. Tables and mineral-type jigs are particularly adaptable to small milling operations that can be applied at mines in less developed areas. The role of handcobbing in beneficiating ores from small mines has been described. As a next step toward greater production, gravity methods of concentration can replace handsorting and cobbing, provided either fresh or salt water is available. The capital investment is modest: A small crusher would replace hand breaking of ore, a locally built heavy-media separating vessel would replace handsorting, and if a market exists for fine concentrates, a shaking table would be installed to recover mineral from fine-size material that previously was stockpiled. Crusher and table would be power driven, and all other operations would be performed by hand labor. If handsorting and cobbing was profitable, the proposed scheme of partial mechanization should be more so; as justified by increased ore reserves, further expansion of mechanized mineral-dressing facilities would be a logical next step. This hypothetical example illustrates the possible use of modern gravity concentration techniques in the simplest way. An iron ore beneficiation plant recently built in Liberia includes 384 spiral concentrators and 64 shaking tables in an operation that illustrates large-scale use of similar techniques in what was truly an undeveloped area.

Froth Flotation

17. The froth flotation process, wherein various organic and inorganic chemicals are used to modify the mineral surfaces to enable a separation of particles in an aerated aqueous pulp because of induced difference in their wettability characteristics, has been in the stage of active development for approximately the past 50 years. Even before much was known about the process in terms of precise scientific knowledge, it had literally revolutionized the ore-processing industry. Now it is big business. In 1960, for example, more than 198 million tons of ore were processed by flotation in the United States.

Some 21.5 million tons of 34 different commodities were recovered in concentrates having a market value of approximately $1 billion. Slightly more than 3 billion kilowatts of electrical energy and 222 billion gallons of water were used in 202 operating plants. And the process is still in the stage of development.

18. Enthusiasm over its potential capabilities for the concentration of minerals was first engendered by demonstrations of its ability to separate mineral constituents of ores with specific gravity and particle size characteristics that prevented satisfactory separation by gravimetric methods. Sulfide minerals of copper and zinc (chalcopyrite and sphalerite), each having nominally the same specific gravity, were separated into marketable products; minerals of lead and zinc (galena and sphalerite) were likewise separated by flotation after liberation by grinding their ores to a particle size range below gravity separation capabilities. Those exciting demonstrations and subsequent operational proof of high mineral recoveries, favorable operating costs, and the simplicity and adaptability of flotation to ore changes quickly elevated the process to the predominant position it still holds in the mineral-dressing industry. Exhaustive experimentation has extended its commercial application to a growing list of minerals, and its capabilities and limitations have been generally defined.

19. Flotation is by no means a panacea for all mineral-dressing problems. On the other hand, it cannot be arbitrarily ruled out as a contending process for the beneficiation of a certain ore on the basis of previously unsuccessful attempts to beneficiate similar-type ores. Every ore, regardless of its apparent mineral or physical characteristics, should be tested in the laboratory to investigate its amenability to the process.

20. Less developed nations can profit in many ways from the extensive and costly pioneering by others in the development of the flotation process Knowledge, gained from experience and scientific research, concerning the beneficiation of every mineral used in industry is available to them, generally in published form, either without cost or at nominal cost; well-equipped mineral-dressing laboratories, staffed by competent and experienced engineers, offer their services to test the amenability of ores for a nominal fee; flotation machines, reagent feeders, and complementary types of equipment that have survived competition from literally hundreds of similar machines thoroughly tested in industry are well known because of their outstanding efficiency and durability and are readily available by purchase; a wide variety of flotation reagents has been developed, tested, and standardized to meet broad requirements of the industry; costly patent royalties for the use of process and equipment have been eliminated with possibly a few exceptions; and expert engineering advice is now a common market commodity.

21. The flotation process is applicable to small as well as large beneficiation operations and should be considered in all cases.

Duplex Processes That Involve Flotation

22. Flotation of reground middling products or tailings from shaking tables, flotation of copper sulfides followed by sulfuric acid leaching of flotation tailings to extract oxidized copper for cementation or electrolytic recovery, and flotation and cyanidation of flotation tailings for gold recovery are examples of duplex processes that evolve from routine laboratory amenability

tests. Three old but generally less familiar duplex processes for copper recovery from oxide or mixed sulfide-oxide ores deserve mention because of possible applications in less developed areas. Two of them, leach-precipitation-flotation and segregation-flotation, are typical techniques that link ore beneficiation with extractive metallurgy.

Leach-precipitation-flotation process

23. Industrial application of the leach-precipitation-flotation process (LPF) for handling mixed sulfide-oxide ores dates back to 1929 operations of the Miami Copper Co. in Arizona. It has since been used by the Inspiration Consolidated Copper Co. and Kennecott Copper Co. in Arizona, the Ohio Copper Co. in Utah, the Anaconda Copper Co. in Montana, and possibly others. In the laboratory it has been used successfully for recovering copper from wholly oxidized copper ores. Its principal attribute is that it obviates a solid-liquid separation and is therefore particularly adaptable to treating oxide copper ores that contain a high percentage of slime-producing materials, as well as to treating mixed sulfide-oxide ores.

24. Optional flowsheets have been used successfully for treating ores. In treating old tailings, the Ohio Copper Co., using minus 35-mesh material, first dissolved the oxide copper with sulfuric acid added to agitators; in a second set of agitators, shredded iron was added to precipitate the copper; after precipitation, the pulp went directly to flotation machines that produced a single concentrate of cement and sulfide copper. At Miami, oxide, carbonate, and silicate copper that remained in the sulfide copper flotation tailings was leached with sulfuric acid and precipitated in the pulp with shredded iron. The cement copper was recovered in a high-grade concentrate by flotation.

25. At Kennecott's operation in Arizona, fine-size sponge iron is used for copper precipitation in place of scrap iron. Pyrite from the sulfide flotation plant is utilized for making sulfuric acid for leaching and for producing the sponge iron.

26. Cost and availability of sulfuric acid and scrap or sponge iron requirements are important economic factors when considering the use of this process. The field of application is obviously limited, but when applicable the process has merit; it is easy to control and offers some advantages in regard to plant costs.

The Copper Segregation Process

27. Laboratory discoveries in 1923 led to the development of the segregation process for recovering copper from oxidized and mixed oxide-sulfide ores. Ores that contain calcite or other acid-consuming gangue constituents that make sulfuric acid leaching of the copper impractical may be well suited to treatment by the segregation process. Pilot plant operations in Peru have shown that the process is economic and efficient for recovering both copper and silver from a manganiferous ore that otherwise is difficult to treat. Tests on a semicommercial scale in Arizona also resulted in a satisfactory report on the economics and efficiency of segregating copper from a calcareous and hematitic oxidized ore.

28. Briefly, the process comprises heating the ore to about 700° C in the presence of a small quantity of sodium chloride and a carbonaceous material, such as coal or coke, to produce fine metallic copper which can be recovered by conventional sulfide flotation methods. Although numerous reactions are involved, basically, the copper is volatilized as cuprous chloride and then reduced to the metallic form at the surface of the carbonaceous material.

29. Although the segregation process has been successfully tested on a pilot plant scale several times, further pioneering remains to be done to commercialize the process. It is, however, an attractive method of treating difficult ores and worthy of continued investigation.

Roast-flotation process

30. A number of duplex processes have been developed which involve low-temperature roasting to improve sulfide flotation separations by superficially oxidizing one or more of the mineral species to be rejected. The separations of cobaltite from pyrite and of molybdenite from chalcopyrite are typical. Another interesting application involves low-temperature dehydration of oxide ores, for example, are difficult to float and require abnormal quantities of collector. Dehydration at 400° to 500° C speeds flotation, reduces collector requirements, and improves manganese recovery. Dehydration aids flotation of most hydrous minerals by increasing reactivity of the mineral surfaces.

The Changing Ore Utilization Pattern

31. The minerals industry, in general, is consuming minerals at an increasing rate while simultaneously insisting upon higher grade and better prepared products. The iron ore industry is typical; an abundancy of high-grade and easily minable ore has given way to progressively low-grade material expensive to mine and difficult to beneficiate, as it did with copper, lead, and zinc. Dwindling reserves of direct-shipping ores in the Lake Superior district have forced the companies to turn to washing and gravity concentration of low-grade ores, and more recently to magnetic concentration of taconite and flotation of jaspilite to maintain production. Approximately 70 percent of iron ore shipments made in 1960 was beneficiated ore, compared with only 30 percent in 1950. With the increase in beneficiation and availability of high-grade imported ores, containing 60 percent or more iron, the iron ore consumers were no longer content to accept, without penalty, the traditional direct-shipping grade of 51.5 percent iron. This has proved to be good business. The increase in capacity gained from use of high-grade and better prepared furnace feed, with a commensurate saving in labor, coke, and flux, has greatly improved the overall economics of iron ore utilization.

32. The change in the utilization pattern for iron ores is illustrative of what logically may be expected of other mineral commodities. New and more efficient beneficiation techniques will be necessary to supply the mineral-consuming industries with products tailormade to fit rigid physical and chemical standards.

Role of Chemical Extractive Metallurgy in Ore Utilization

33. The progress made in physical beneficiation has been paralleled by similar improvements in extractive metallurgy. Some of the more significant

recent advances have resulted from the application of chemical processing methods to minerals. Extraction and recovery of uranium, vanadium, rhenium, columbium, zirconium, and the rare-earth elements by ion exchange and solvent extraction, for example, have changed many former concepts about ore processing. New methods have been devised for direct leaching of sulfide ores and concentrates, volatilization techniques have been improved and perfected, new solution purification procedures have been devised, and better and more efficient product recovery methods have been developed. A new discipline of chemical extractive metallurgy has emerged which seems destined to replace some of the older processes and enable practical treatment of still lower grade and more complex ores. Chemical upgrading rapidly is becoming an integral part of the minerals beneficiation field.

Ion Exchange and Solvent Extraction

34. The application of ion exchange and solvent extraction for recovery and purification of uranium from low-grade ores and concentrates was the beginning of a new era in hydrometallurgy. Although the techniques had been used earlier for industrial purposes, including water softening, refining lubricating oils and gasoline, fractionating vegetable oils, and manufacturing pharmaceuticals and antibiotics, the potentialities of ion exchange and solvent extraction in metallurgy were not fully appreciated. The success achieved on uranium gave impetus to broad acceptance of the techniques as useful tools in extractive metallurgy. A partial list of applications includes such diverse separations as uranium from vanadium, molybdenum, iron, and titanium; rhenium from molybdenum; scandium from molybdenum and tungsten; beryllium from iron and aluminum; iron and titanium from aluminum; hafnium from zirconium; cobalt from nickel; tantalum from columbium; thorium from rare-earth elements; and the fractionation of the rare-earth elements.

35. Ability to tailor-make durable and high-capacity synthetic organic resins and liquid ion exchangers from extractions of anionic and cationic constituents gives broad versatility to the technique and suggests increased use in extractive metallurgy as adjunctive processes on low-grade and complex ores. The marked similarity of flotation and ion exchange is apparent; flotation is a physical selector for upgrading ores and ion exchange is a chemical selector for upgrading hydrometallurgical solutions.

36. Ion exchange and solvent extraction processes are expensive, but not unnecessarily so in view of their simplicity and adaptability to separations difficult or impossible by other procedures. An advantage through lower capital or operating costs, better recovery, or higher purity is presupposed to justify their commercial adoption.

Bacterial Metallurgy

37. An interesting recent development in extractive metallurgy is the use of bacteria to promote leaching of copper, manganese, zinc, and molybdenum from low-grade ores. The Thiobacillus thiooxidans, for example, is capable of oxidizing the sulfide in pyrite to form sulfuric acid. Similarly, the Thiobacillus ferrooxidans convert ferrous iron to the ferric state to give an acid-ferric sulfate solution for leaching sulfide and oxidized minerals. Both strains of bacteria are autotrophic and can live on inorganic substances such as dissolved salts, nitrogenous material, carbon dioxide, and oxygen present in

natural water. Improved strains of the bacteria have been developed through cultures that are tolerant to high acid and metal salt concentrations. Work underway at the Bingham mine, Kennecott Copper Corp., has demonstrated that bacterial inoculation speeds materially leaching of oxidized and sulfide copper minerals from the mine waste dumps. Other research has shown that bacterial oxidation accelerates leaching of sphalerite, molybdenite, and various manganese oxides.

Dry Concentration

38. Asbestos and magnetite mineral beneficiation and concentration by dry methods are common procedures. Wet and dry duplex processes are more generally used in the United States for final separation and cleaning of gravity and flotation concentrates to trade specifications. High-intensity magnetic separation to clean glass sand and battery-grade manganese, electrostatic separation of silica from phosphate flotation concentrates, and fractionation of beach sand concentrates by magnetic and electrostatic methods are typical applications.

39. Mineral-bearing sandstones are exceptions to the general rule that low-grade and disseminated ores are not amenable to dry concentration. Dry methods have been used for concentrating certain uraniferous, ferruginous, and copper-bearing sandstones composed of silica grains cemented with the softer uranium, iron, copper and phosphate minerals. Dry attrition grinding and air classification, sometimes supplemented by pneumatic tabling of intermediate middling products from the air classifiers, will often yield satisfactory results in treating ores which do not respond readily to treatment by flotation or other wet processes. Air jigs and pneumatic tables are obtainable from manufacturing firms that specialize in this type of equipment and publish descriptive information and engineering data relative to their operation.

40. Dry concentration is an attractive process for special applications in regions where water is scarce or entirely lacking. One prerequisite to a successful operation is that the material treated must be dry; if fuel is required for removing moisture the additional cost will be an economic disadvantage to dry processing. Other advantages and disadvantages should be investigated and understood before a decision regarding dry processing is made.

Water and Pollution Problems

41. For other than dry methods of ore beneficiation the quantity and quality of water available may limit plant size and govern choice of the flowsheet. The quantity of water required varies considerably for different mills and may range from 10 tons per ton of feed in ore washers and gravity concentrators to approximately 2 tons in sulfide flotation plants. With few exceptions, water recovery is general practice. If the tailings must be impounded to avoid difficulty arising from pollution of water used elsewhere for agricultural or municipal purposes, part of the tailing pond water may be recycled if economically advantageous. The unretrievable water lost by evaporation from the tailings pond is serious only in arid regions, and loss from seepage can be minimized by sealing porous strata with slime or clay. With reasonable care, recovery of up to 70 percent of the process water for return to the mill circuit generally is possible. The recovered water seldom is crystal clear, but the solids content can be controlled within reasonable limits by flocculation of the slimes with lime, starch, glue, various natural gums, and synthetic organic flocculents, such as the polyacrylamides, which are widely used for solid-liquid separation in the mining and metallurgical industries.

42. The permissible quantity of water that can be recycled is greatest for gravity circuits and least for flotation because of buildup of soluble salts and unconsumed reagents which destroy selectivity and reduce recovery. The tolerance toward contaminated water is least in fatty acid flotation of nonmetallics and greatest in bulk flotation of sulfide ores. Selective flotation processes are sensitive to changes in composition of the recycled water, and frequent reagent adjustment may be necessary to maintain selectivity. Water treatment is expensive but may be necessary if an adequate supply of good-quality water is not available for the flotation circuit.

Exploitation of Mineral Resources in Less Developed Areas

43. A hypothetical example of using handsorting and gravity concentration methods to help develop a prospective mine has been given previously. By American tradition, this is referred to as a "bootstrap" or "make pay as you go" approach. Many mineral prospects have been developed into highly profitable commercial operations by little more than man's ingenuity, perseverence, and hard work. In many instances, beneficiation of the ore was necessary and usable methods were limited to handsorting or simple gravity concentration with rockers, sluiceboxes, or shaking tables until the prospect was developed into a mine and a more elaborate treatment plant was justified. Mention of this simple approach does not imply that less developed areas need revert to primitive methods to start developing their mineral resources, although such methods should not be overlooked. Rather, it suggests that a careful study be made to delineate the scope and nature of the specific mineral problems of the particular area and that a choice then be made of those segments of advanced technology that can be applied or modified to meet the particular problems involved.

44. The problem of beneficiating ore in remote areas, for example, has been greatly simplified by the development of mobile and portable beneficiation plants of different sizes. The plants are unitized, and the individual pieces of machinery have been designed for transportation by primitive means. Complete plants are available for crushing, screening, and grinding, alone or in conjunction with different types of gravity, amalgamation, cyanidation, magnetic, and flotation unit operations. Diesel and gasoline powerplants of unitized construction also are available. In the less developed areas, such plants will have unique advantages as pilot mills that can be expanded into permanent plants or dismantled and moved to test other more favorable deposits.

45. Another kind of plant that merits consideration for less developed areas is the custom mill, a mill designed and built to process ores from several mines located generally in the same district. The operators of such mills may either purchase ore outright on the basis of its assay value or process the ore for a flat fee per ton and either return the products to the owner or arrange for their sale under a cooperative marketing plan. Such mills have operated successfully in the United States and other countries. In Peru, at least five custom mills have been built and operated by a Government agency in widely separated districts to process ore from several mines and indirectly to provide a market for the ore without which the mines would have remained idle. For such mills to be successful there must be some certainty that sufficient ore is available for treatment in the district to pay out the cost of the plant and to keep it operating on a scale that will be profitable for plant operator and miner alike.

46. The lack of skilled labor and technicians has been cited as a deterrent to mineral development in certain areas. The problem is real but perhaps overemphasized. People learn rapidly by imitation and can be easily trained to operate a jackhammer, a jig, or a flotation machine. It is essential, however, that a nucleus of highly trained and proficient engineers of all disciplines be available to plan and direct the mineral development programs.

47. This points to the need for better dissemination of technical information on a worldwide basis and formal mineral-dressing education for those who will be responsible for adapting mineral-dressing techniques to the beneficiation of minerals in less developed areas. It should be added here that other needs exist, principally for laboratory facilities having basic equipment units for testing the amenability of ores to beneficiation by methods in general use and for facilities for fire assaying and chemical analyses of ores.

Dissemination of Technical Information

48. Scientific and engineering progress in mineral dressing and extractive metallurgy has been faithfully recorded from infancy to its present state of maturity in technical periodicals, published proceedings of professional organizations, textbooks, and other publications, including those of Government agencies.

49. Most of this information is preserved in technical libraries located primarily in the industrialized nations. In many new nations documentation facilities are not available for general use and frequently the professional ore dresser is obligated to work without adequate knowledge of what is going on or what has gone on in the rest of the world. A central source of published information on old as well as new process techniques and practices that is equipped to function on a worldwide basis is an obvious need. It should include among its facilities an automated information retrieval system, a duplication service, and unlimited translation capabilities. It should serve particularly the needs of less developed nations. International group action, by providing this service, can make an outstanding contribution to the technical advancement of new nations.

Mineral-Dressing Laboratory Facilities

50. It has been suggested that laboratory facilities are needed in less developed areas. In order of priority this need follows that of education. To equip such laboratories is relatively simple, so simple in fact that a great many have been established throughout the world and have since remained idle for lack of a technical staff to direct their use. To staff a laboratory with capable technologists is not a simple matter and this problem should be resolved before commitments for physical facilities are made. In establishing a mineral-dressing laboratory a modest approach is the best approach. Its planned purpose should be limited to the testing of ores for their amenability to beneficiation by the better known and more widely used methods of mineral dressing, and if this is done the requisite equipment, apparatus, and supplies will be kept to a minimum. An analytical section will be an essential adjunct to the mineral-dressing laboratory.

51. Without modifications and imaginative applications corresponding to actual needs, the potential benefit of advanced mineral-dressing methods to less developed nations cannot be fully realized.

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